Chapter V

Increased Efficiency

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INTRODUCTION

The potential for reducing energy use through increased efficiency—energy conservation-is one of the truly new public policy concerns of the past decade, Historically, the United States has simply shifted from one supply source to another as declining supplies or other concerns shifted consumer preference. Graphs showing U.S. energy use reflect similar steps from the use of wood to that of coal and then to oil. While basic engineering progress ensured the improvement of fuel efficiencies to some degree over time, the availability of low-cost, high-energy value fossil fuels in the country meant that there was little reward for using fuels in a frugal manner. Operating costs of U.S. energy-using systems —transportation, buildings, industry—were, in most cases, very small compared to the large first-costs of cars, homes, and plants. Accordingly, energy conservation commanded little research attention and no policy concern until after the 1973 embargo.

The rising prices and the specter of insufficient supply that followed 1973, however, set in motion a flurry of research, policy effort, and private commitment to pay attention to the cost of energy and to lower that cost through improved efficiency in design and process. Substantial research talent was allocated to find ways to meet energy end-use needs with less fuel. Early analysis indicated that there was in fact a substantial savings to be had at costs that were much lower than the likely costs for providing increased supply —in part because of the historical disinterest in the issue. This was the case, according to these analyses, in all sectors of the U.S. economy.

In addition to private investment and marketing efforts throughout the 1970s, the Federal Government approached conservation through all policy channels—subsidy, information transfer, and regulation. A wide variety of programs was authorized and funded.[1] State and local energy offices sprang up as well, and conservation was often a principal emphasis of these programs.

The rapid learning curve on conservation and its many positive characteristics made it popular with many policy makers. The positive characteristics of conservation include:

1. The ability to use a wide range of techniques to solve the site-specific efficiency problems.
2. Small scale and an emphasis on existing technology allowed for quick implementation.
3. Conservation options that were cheaper than many supply options to meet heating needs, and often do not require the large capitalization of a large-scale supply technology.
4. Excellent returns or investment in efficiency options through savings on future fuel cost increases (the higher fuel costs rise, the faster the return).
5. Potential for avoiding protracted conflicts over the siting of new supply facilities, such as power lines and generating plants, if requirement for new supply is reduced.
6. Benign environmental impacts compared to those from extractive fuel technologies, both at extraction and use points.
7. Possibility for local and individual decision-making and control.
8. Creation of jobs in manufacturing, installation, auditing, and related skills.

[1] Federal R&D *Funding for* Energy: Fiscal Years 1971-84, National Science Foundation, Special Report, February 1983. "Energy conservation projects reflected the steepest gain of all energy R&D programs during the 1974-80 period, moving from $9 million to $264 million. The chief thrust was toward improved efficiency of energy use in transportation, especially automobiles. A substantial share of the effort was also aimed at buildings and community systems, and at industrial systems, to be cost-shared with industry. The present administration, in the belief that strong financial incentives exist within the economy to develop technically and *economically* promising technologies, has reduced conservation activities to a single program under the heading of energy conservation research; industrial, transportation, and buildings and community systems programs have been completely eliminated. Proposed R&D funding for energy conservation was $19 million in the 1983 budget. The average annual decrease of 58.5 percent for conservation support in the 1980-83 period was the greatest of any energy program."

While American energy use for all applications has been dramatically reduced (on a per capita or other appropriate basis), the portion of the reduction directly attributable to investments in improved efficiency is the source of some debate. Methods for measuring actual end-use behavior are not in place, and the isolation of a single variable is extremely difficult. For example, consider personal travel. The 1975 Energy Policy and Conservation Act set fuel economy standards for automobiles. Very substantial savings have resulted from these standards and a shift in market demand to smaller (more efficient) vehicles, and the savings will continue and increase as the stock of automobiles is turned over throughout the 1980s. An additional factor in gasoline use, however, is vehicle miles traveled. A large portion of gasoline savings between 1978 **and 1980 appears to have resulted from a reduction in vehicle miles traveled. Similarly, energy** use per unit output in industry has dropped, but it also appears that the market basket of products has altered to reflect a mix of products that are simply less energy-intensive.

Without doubt the most complex area of analysis on the impacts of conservation has been in energy use in buildings, and in particular in the residential sector. U.S. energy use per household is now strikingly below the levels predicted even in the mid-l970s. There is growing evidence, however, that most of this reduction is due to less use and not to more efficient homes. Changing patterns of household formation, shifting work schedules, and other factors are also important. All of these factors are strongly connected, however, and difficult to quantify separately.

In fact, one of the principal difficulties associated with conservation policy questions has been the issue of measurement. While it is quite simple to measure new supply–a fuel is either produced or it is not–the attribution of savings to specific actions is complex.

These measurement and attribution problems aside, however, the response to energy conservation opportunity stands as one of the striking aspects of energy use in 1983, as opposed to that in 1973. Energy conservation is now a criterion in many investment decisions. Problems of implementation now substantially outweigh problems in technology development, although there are still many technical unknowns. Readers interested in detailed analysis of the technical and implementation issues relating to conservation are encouraged to refer to the following OTA publications: Residential Energy Conservation, The *Energy Efficiency of Buildings in* Cities, ndustrial *Energy Conservation,* and *Increased Auto*mobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing oil Imports.

BUILDINGS

Energy use in the residential and commercial sectors is largely determined by the stock of buildings. In 1980, the residential sector consisted of 80 million households, an amount expected to increase to 95 million units by 1990. In the commercial sector, there are about 4 million buildings, with a total floorspace of 44.7 billion square feet (ft[2]). Total floorspace is expected to grow to 57.7 billion ft[2] by 1990.

In both sectors, natural gas is the major fuel used, primarily because it is relatively inexpensive, clean, and easy to handle. In 1980, residential gas use was equivalent in energy to **2.4 million** barrels per day (MMB/D) of oil, or 52 percent of total sector energy use. The Energy Information Administration (E IA) projects that natural gas will remain the primary residential fuel through 1990, but its share will decline. By 1990 electricity is projected to replace natural gas as the primary fuel in the commercial sector.

Today, electricity use is second only to natural gas in both the residential and commercial sectors. Electricity is used primarily for nonheating purposes, for example, in air-conditioning, lighting, cooking, and refrigeration, etc. By 1990, EIA estimates that residential electricity use will in**crease to about one-third** of all sector energy used, principally due to greater use of electricity for space heating. In the commercial sector, 1980 electricity use was equivalent to 1 MMB/D of oil, and EIA projects that this figure will increase to 1.4 MMB/D energy equivalent in 1990. This projected rise in commercial sector electricity use is largely due to an increase in office and retail/ wholesale office floorspace, particularly in the South and West regions, which are heavily dependent on electricity.

About 14 million residential buildings use oil (including kerosene) for heating and hot water; consequently, the total oil used in the residential sector is relatively small. In 1980,0.7 MMB/D of oil, or 15 percent of all energy, was used in residential buildings. EIA projects that oil consumption will decrease slightly, declining to a little over 0.6 MMB/D by 1990. On a regional basis, the highest percentage of heat from oil is found in New England, followed by the Mid-Atlantic region. EIA data show that the percentage of oil used for heat in homes is twice as high in urban as in rural areas. Most of these homes are under **2,000 ft^2 and were constructed before 1959.**

Like the residential sector, the percentage of commercial buildings using heating oil is small—**20 percent, or 762,000 buildings—and is concentrated in the Northeast. Moreover, the EIA projects that** fuel oil use in the commercial sector will increase throughout the 1980s. **In 1980, this sector consumed 0.6 MMB/D and is projected to consume 0.7 MM B/D by 1990. Projected growth in floorspace will offset the improvements in efficiency and conversion to other energy sources. By 1985, residential and commercial oil consumption is projected to be about 1.3 MMB/D with about half being consumed in each sector.**

As stated previously, natural gas accounts for a much larger share of the buildings sector total than oil. Even though the natural gas share declined in 1982, **it still provided almost half (48 percent) of total energy,** while oil provided about 17 percent. Furthermore, as discussed in chapter III, oil consumption by residential and commercial users accounted for only about **8.3** percent of total U.S. oil consumption. Consequently, energy conservation in homes and commercial establishments will likely have a much greater impact on demand for natural gas than for oil.

Heating Oil Conservation

To estimate potential oil savings through investments in energy conservation in residential and commercial buildings, OTA first determined energy use by fuel for each sector separately from 1981 EIA State energy use data. These totals were aggregated into the 10 Department of Energy regions (see table 17). Next, OTA assumed that petroleum demand in these two sectors would be near the 1981 level when the hypothetical disruption occurs in 1985, This assumption means that oil demand rebounds from its 1983 low. Current EIA projections are in accord with this assumption.

In these two sectors, oil is used primarily **for both space and water heating in buildings. About 80 to 85 percent is** used for space heating, and the remainder for water heating. The calculations that follow concentrate on the space heating portion.

OTA will also carry out the calculation of oil conservation potential independently of the estimate for fuel switching which of course is going on at the same time. Initially, building owners will probably invest in either or both conservation and fuel switching when they see the price of oil escalate rapidly as supplies are suddenly reduced. Instead of making any assumptions about the separate contributions of the two types of investments, OTA calculated each alone, as if the other were not occurring, and then combined the two and eliminated the overlap. This last calculation is described in chapter VI.

Table 17.—Assumed 1985 Oil Consumption in the Residential and Commercial Sectors, by Region (thousand B/D)

	Residential	Commercial	Total
Region 1	133	50	183
Region 2	145	99	244
Region 3	129	43	172
Region 4	81	50	131
Region 5	151	54	205
Region 6	25	113	138
Region 7	47	16	63
Region 8	18	7	25
Region 9	11	51	62
Region 10	26	9	35
Total	766	492	1,259

SOURCE: Office of Technology Assessment, Conservation in buildings can be achieved by a number of means that reduce the energy requirements of the building and its appliances, increase the efficiency of energy-using equipment, or some combination of each. For this analysis, OTA considered only those investments that would directly reduce heating oil requirements and that would have the greatest effect in the largest number of buildings. For residential buildings, analysis and post-retrofit data to date show that the combined effect of insulation in ceilings and walls and replacement of existing burner assemblies on oil furnaces with high-efficiency burners are the most cost-effective options for reducing oil use. The data indicate that oil use for space heating can be reduced by about 25 percent for an average unit.

In contrast, the potential for insulation to reduce oil consumption in commercial buildings is much more limited. For example, owners of large commercial buildings with clad walls and flat-roofed buildings with no cavity above the ceiling will find adding insulation to be a rather unattractive investment. Replacement of burners, however, will be quite cost effective, and will reduce oil use for heating about 20 to 25 percent on the average. There are other opportunities for commercial buildings such as conversion of terminal reheat forced-air systems to variable air volume systems and installation of stack heat reclaimers for heating systems that use water. Only the replacement of burners, however, offers cost-effective improvements in heating efficiency for all types of commercial buildings and heating systems.

The next step in determining potential oil savings is to estimate the number of buildings that can be retrofitted[2] during the 5-year period. In the residential sector OTA assumed that one-third, or 4.5 million homes, will be reached, This number is somewhat arbitrary and recognizes that many of the oil-burning homes in the country are not capable of being insulated or are already insulated to the levels OTA assumes. In the former category, there are many homes for which wall insulation is not feasible because there are no cavities in which to place insulation. In addition, a number of homes would require extensive repairs before insulation could be effective.

For commercial buildings, OTA assumed that all **762,000** buildings were reached. The much smaller number of buildings combined with the limitation on replacing burners in commercial buildings was the basis for this assumption. Again, the choice is somewhat arbitrary. As will be seen in the next chapter, about 80 percent of the oil used by all buildings is determined to be replaced by alternative energy sources. Therefore the amount of oil that is" replaced" by conservation is small, and errors introduced by an incorrect estimate of the number of buildings actually retrofitted with insulation and/or new oil burners

‘Retrofit means to install additional or replacement equipment in an existing building.

Photo credit: U.S. Department of Energy

Insulation material is blown into the wall cavity to increase the energy efficiency of this building

Table 18.-Potential Oil Replacement by Energy Efficiency Investments in the Residential and Commercial Sectors (thousand B/D)

DOE region	1985	1986	1987	1988	1989	1990
1		8	15	19	21	23
2	0	8	18	25	31	37
3	O	6	12	16	20	22
4	O	8	10	16	17	19
5	o	7	14	18	23	26
6	O	8	16	21	27	30
	0	2	4	6	6	6
8	o	2	3	3	3	
9	0	5	8	10	12	14
10	0	2	4	5	5	5
Total = 185,000 B/D						

SOURCE: Office of Technology Assessment; base consumption data Energy Information Administration.

will be even smaller, less than 10 percent of the oil used in 1985.

Using the above assumptions, OTA calculated the oil displacement schedule in buildings by region from 1985 through 1990. These figures are shown in table 18. The total oil displaced at the end of the 5 years by conservation is about 185,000 barrels per day or about 15 percent of the total used for space heating in 1985 **by all buildings.**

OTA estimates concerning the number of buildings that could be retrofitted over the 5 years were determined by limitations imposed by the physical state of the buildings themselves, because the principal source of conservation is the insulation of the building shell in the case of residential units. These estimates must now be compared with the constraints presented by the manufacturing capacity of insulation and replacement burners and by the personnel needed to audit these buildings and install the equipment. Because OTA dealt only with equipment and not with the physical condition of the structure, we did not need to go through this two-step process in that case. Personnel limitations, however, were factored in.

OTA first determined whether sufficient additional insulation could be made available during an oil disruption to meet the requirements calculated above. Assuming a floor area of 1,200 ft^2 and a wall area of 935 ft^2 for a typical house, R-30 insulation in the ceiling and R-11 in the walls, about 46,000 R-ft^2 of insulations is needed per house, or a total of 216 billion R-ft^2 for all the residential buildings insulated over the 5 years. In 1977, estimates of annual production capacity for fiberglass insulation ranged from 100 billion to 160 billion R-ft^2. In addition, the industry expanded its production capacity in 1979 after the increase in oil prices. Therefore, no apparent constraints to meeting the insulation requirements for oil-heated homes at least, exist.[4]

Burner production capacity also appears to be sufficient. The number of replacement burners required is about 5.3 million over the 5 years. Current production capacity is about 1.5 million a year. Therefore, as long as the replacement is phased in over the entire period, there will be no shortage. It must be noted that the fuel switching calculation for buildings described in the previous chapter required over 8 million replacement burners to switch from oil to natural gas. This apparent constraint is not real, however, since only those oil users not converting to other fuels–less than 1 million–would actually need new oil burners. **In other** words, when conservation and fuel switching are combined, about 9 million new, high-efficiency burners are required in total. With a modest growth in production capacity (9 percent per year), this amount could be supplied in the 5-year period.

Perhaps the greatest constraint to achieving the oil savings target is the large amount of auditing and retrofitting which will be needed. This, in turn, will require a large increase in personnel over current activities. In recent years, there has been a decline in the number of private firms offering these services, however. Many have gone out of business or shifted their efforts to the commercial sector because of decline in demand for retrofits to residential buildings. Although a shortage of knowledgeable auditors may exist immediately after the disruption, a large number can be trained and on the job within a short period of time. The current industry standard for training auditors is about 6 to 8 weeks, including both specific training and some on-the-job, supervised time. Quality control, however, both in training auditors and product installations and performance, may be a serious problem.

To see whether audits and retrofits can be performed at the rate required to achieve the conservation targets, OTA examined the recent history of audit and retrofit programs. Under the Residential Conservation Service, mandated by the 1978 National Energy Conservation Policy Act, nearly 2 million audits were conducted by local electric or gas utilities from April 1981 to March 1983.[5] This figure does not include many of the audits conducted by two of the largest and

[3]**R-ft^2 is a measure of the wall or ceiling area being insulated times the R value (insulation properties) of the insulating material.**

[4]**Residential Energy Conservation (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-E-92, July 1979), p. 283.**

[5]Eric Hirst, *Evaluation of Utility Home Energy Audit (RCS) Programs,* **Oak Ridge National Laboratory, February 1984, p. 3.**

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most active utilities: the Tennessee Valley Authority (TVA) and the Bonneville Power Administration (BPA). Between 1977 and 1983, TVA and BPA conducted 750,000 and 209,000 audits, respectively. **In addition, TVA weatherized 350,000 units during that period. A large number of audits were also completed by other utilities over the last 5** years. For example, Pacific Gas & Electric audited more than 350,000 homes and weatherized over 315,000 of them. Since 1981, the Mass Save program sponsored by 48 utilities in Massachusetts and Connecticut conducted 166,000 audits, and Pacific Power & Light conducted 66,000 audits and weatherized nearly 29,000 homes. Many others were probably retrofitted, too, but were not reported by the utility since they were done by private contractors or were done by the homeowners themselves. While a national total is not available, it appears from this sample that there will be sufficient personnel to perform the necessary audits and retrofits. This is especially likely if the retrofits are confined to installation of insulation and/or replacement burners.

For commercial buildings the problems of having sufficient numbers of qualified personnel to perform the necessary audits and retrofits are probably lower since there has been much more interest in investing in commercial buildings than in residential buildings for greater efficiency. In fact, it is likely that the potential for lowering oil use by conservation in these buildings may be lower than the 25 percent OTA assumed because substantial changes have already been made. The error will not be large when fuel switching is accounted for, however, since the net contribution of conservation will be much lower than in the case of no fuel switching.

Natural Gas Conservation

Although OTA concentrated its analysis on oil, OTA expects that building owners who use natural gas will also undertake conservation efforts during the 5-year period. Because of the large volume of natural gas used by buildings, even a modest success in conservation will provide a large quantity of natural gas for use as a replacement for fuel oil. About 46 million households and 1.9 million commercial buildings use natural gas as a heating fuel. **In 1981 about 4.9 trillion cubic feet (TCF) of natural gas was used to heat these buildings. An additional 2.6 TCF was used** for other building energy services, primarily water heating and cooking. If 10 percent of the heating gas were conserved over the 5 years, nearly 0.5 TCF/yr would become available at the end of the 5 years, which would be about 25 percent of the total that OTA estimates will be used for fuel switching. The availability of that conserved natural gas can be very important in easing any pressures that may arise if domestic natural gas production were to drop rapidly by 1990.

Obtaining a 10-percent reduction in natural gas use, however, will require levels of insulation in residential buildings and replacement burners in commercial buildings that may stretch the production capacity limits of those two items. If the 25-percent reduction in heating fuel requirements per building that OTA assumed for the oil case can be achieved, about 18.6 million residential units will have to be insulated. This would amount to 845 billion R-ft^2 of insulation, which, when added to the requirements for oil, would exceed the upper end of the range of 1977 production capacity. The expansion in production capacity since 1977, however, coupled with the potential for expansion during the 5-year period (the leadtime for capacity expansion ranges from 12 to 36 months) and the production capacity for other types of insulation—e.g., cellulose, rockwool—should be sufficient to meet the combined demands of oil- and natural gas-heated homes. Problems may occur if there is also substantial demand for electrically heated homes, although those homes are usually better insulated than homes heated by oil or natural gas.

Supplying the other major conservation technology, replacement burners, should not present any problems if one assumes that they will be needed only for natural gas-heated commercial buildings. This is a plausible assumption since residential buildings can achieve the 25 percent savings with increased insulation alone, while insulation will be far less effective for commercial buildings, for reasons stated above. The type of burners that would improve the efficiency of natural gas-fired furnaces are somewhat different than those needed for oil-fired furnaces because the latter require atomization of the fuel, while the gas burners do not. The principles behind increasing combustion efficiency, however, are the same for both types—e. g., increasing flame turbulence and residence time–so there should not be any significant difference in manufacturing capability between the two. With this assumption, therefore, about 1.9 million replacement burners would be required, which would be added to the 9 million for increased efficiency and conversion to natural gas of oil-heated buildings. The sum, about 11 million, could be produced over 5 years if production capacity increased by about 19 percent per year, starting with a 1985 production capacity of 1.5 million units per year. This growth rate is high enough, however, that there will probably be some limitations due to burner availability, although manufacturing is sufficiently simple that this growth rate could be achieved. The result of the burner production limitation would be to reduce the amount of natural gas available by conservation. Given that case, conservation in other uses of natural gas—cooking and water heating–would have to make up any differences that may be needed. The large amount used in those categories, combined with many opportunities to increase efficiency there, makes it reasonable that such gas can be made available.

TRANSPORTATION

In 1980, the transportation sector consumed about 9.6 MM B/D of oil (see table 19), The main fuels consumed were gasoline (6.5 MMB/D oil equivalent), primarily for automobiles (4.6 MMB/D) and trucks (1.7 MMB/D), diesel (1.4 MMB/D), jet fuel (1 MMB/D), and residual fuel oil (0,7 MMB/D). In addition, OTA estimates that about 0.5 MM B/D were consumed by the industrial sector in off-road construction, mining, and agricultural machinery and equipment.

Consumption of gasoline, the dominant transportation fuel, peaked in 1978 at **7.4** MMB/D (including 0.1 MM B/D for nontransportation purposes). By 1979 it had dropped to 7.0 MMB/D and in 1980 it was 6.6 MMB/D. In OTA's judgment, only about half of this drop can be attributed to the increased efficiency of vehicles on the road; the other half must be due to a reduction in the vehicle miles of travel (VMT). Between 1980 and 1983, gasoline consumption has remained nearly constant because the continued increase in fuel efficiency has apparently been offset by increases in VMT. By 1983, VMT had returned to its 1978 level; and unless it continues to rise, gasoline consumption is likely to drop to around 6 MM B/D by 1985.[6] Consumption of other transportation fuels in 1985, on the other hand, is likely to be similar to its 1980 level.

All but about 0.1 MMB/D of the diesel and residual oil used in the transportation sector is for freight transports. OTA has not assessed potential fuel savings in freight transports, but a recent Argonne study indicated that fuel consumption could be reduced by 4 to 8 percent in an oil shortfall, starting in mid-1981 and similar in magnitude to the one postulated in this study.[7] The savings could be achieved through a variety of measures, including shifts in the mode of transportation (from air to truck, truck to rail, and rail to marine), changes in operating practices (e.g., less idling, compliance with speed limits, fewer empty runs, improved maintenance), and technical changes (e.g., different types of air filters, lubricants, tires; aerodynamic devices; temperature-controlled fans). Although some of these changes will have been implemented by 1985, the timeframe considered here (5 years) is longer than that considered in the Argonne study (1 year). Moreover, some older vehicles can be replaced with newer, more efficient models. The savings from fleet turnover, however, is likely to be considerably less than for passenger cars because transport

[6] This assumes that the average fuel efficiency of new cars sold in 1985 will be 27.5 miles per gallon (mpg) and that the percentage efficiency increase in light trucks on the road will be half as large as that for automobiles.

[7] L. R. Johnson, et al., "Energy Contingency Planning for Freight Transportation," Argonne National Laboratory, ANL/CNSV-34, August 1982.

Table 19.–Transportation Oil Use by Mode and Fuel Type, 1980

	Fuel consumption (M MB/D)			
	Gasoline	Distillate fuel oil	Jet fuel	Residual fuel oil
Highway use	6.3	0.9	—	—
Motorcycles and mopeds	0.02	—	—	—
Automobiles	4.6	0.03	—	—
Buses	0.03	0.04	—	—
Trucks		0.9	—	—
Nonhighway use	0.15	0.4	0.8	0.7
Air	0.03	—	0.8	—
Water	0.1	0.08	—	0.7
Rail	—	0.3	—	0.002
Snowmobiles	0.01	—	—	—
Military operations	0.01	0.07	0.2	—
Total	*6.5*	*1.4*	1.0	0.7

SOURCE: Adapted from G. Kulp and M.C. Holcomb, "Transportation Energy Data Book, Sixth Edition," Oak Ridge National Laboratory, ORNL-5883, 1982.

vehicles are kept longer than carsa and the difference in efficiency between new transport vehicles and the average transport vehicle already on the road is less than for cars. Consequently, savings of the magnitude of 4 to 8 percent are probably still reasonable.

Although the engines in off-road vehicles and equipment used in construction, mining, and agriculture (CMA) are similar in many respects to those used for some types of freight transport, many of the adjustments (e.g., shifts in transportation mode) are not available to users of industrial engines. Consequently, the percentage of savings from increased efficiency in CMA machines and equipment is likely to be considerably smaller than that in freight transport; and OTA has not included any savings in the area of CMA machines and equipment.

Passenger aircraft consume about 75 percent of all jet fuel and over 98 percent of the jet fuel consumed by nonmilitary aircraft. Reductions in fuel consumption by passenger planes can be achieved by reducing the weight of interior equipment (e.g., seats, shelves), operating planes with fewer empty seats, removing exterior paint to reduce aerodynamic resistance, and other changes. Also, some planes will be replaced by newer, more efficient models. Again OTA has not assessed potential fuel savings in passenger planes, but if their fuel consumption could be reduced by 5 to 10 percent, the total savings in freight transport and passenger aircraft would be about 0.1 to **0.2** MMB/D.

Considerably larger savings are likely in passenger cars and light trucks. g Because the auto industry has been changing production facilities to produce more efficient cars and light trucks for a number of years, fuel consumption will drop between 1985 **and 1990, with or without an oil disruption.**

To illustrate the probable magnitude of the fuel savings, OTA has calculated three scenarios for automobile fuel consumption, shown in figure 35. In each case, it was assumed that the VMT are proportional to the number of automobiles on the road (i.e., average miles per vehicle is constant, as has roughly been the case historically).[10] It was also assumed that the average fuel efficiency of new cars sold in 1985 **will be 27.5 mpg.**[11]

In the base scenario (A) OTA assumed that the number of automobiles will increase by 5 percent between 1985 and 1990, that new car sales will average 11 million vehicles annually, and that the new car fuel efficiency in 1990 **will be 27.5 mpg.** For the disruption scenarios (B and C), OTA

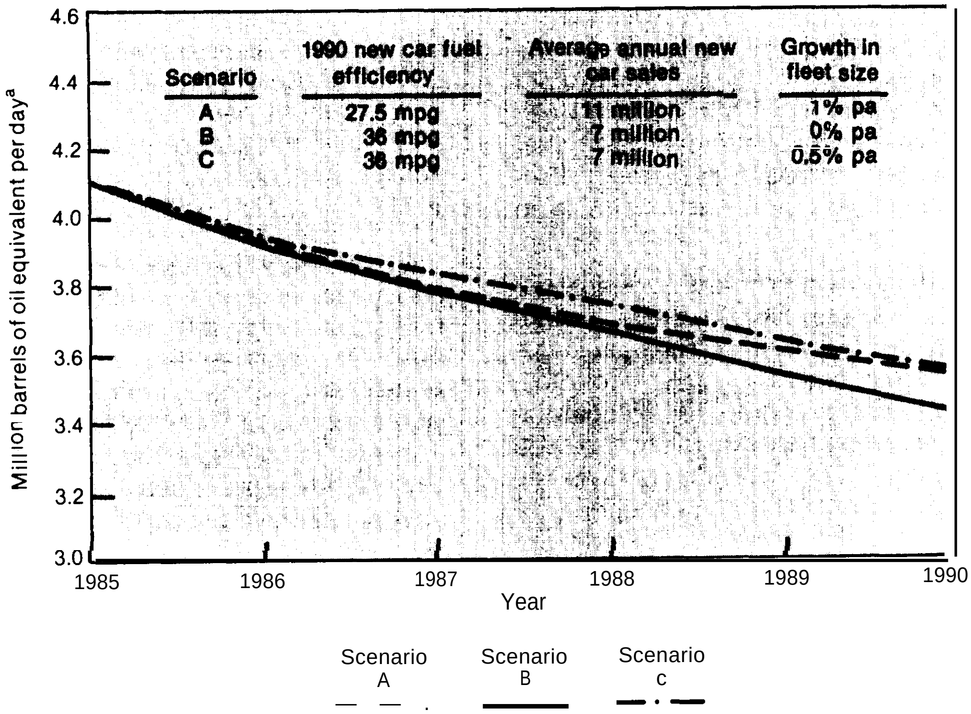
*G. Kulp and M. C. Holcomb, "Transportation Energy Data Book, Sixth Edition, " Oak Ridge National Laboratory, ORNL-5883, 1982.

[9]*Increased Automobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing Oil Imports* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-E-185, September 1982).

[10]Kulp and Holcomb, op. cit.

[11]EPA composite fuel efficiency, consisting of 55 percent city and 45 percent highway driving cycles. Actual on-the-road fuel efficiency is assumed to be 10 percent lower than this.

Figure 35.—Automobile Fuel Consumption Projections, 1985-90



[a]At 5.5 million Btu per barrel of oil

SOURCE: Office of Technology Assessment.

assumed that annual new car sales are depressed, averaging 7 million vehicles, and that the new car fuel efficiency in 1990 **is 36 mpg, reflecting a market demand for** more efficient vehicles. In scenario B, the automobile fleet size remains constant, while in scenario C, it grows by 2.5 percent between 1985 **and 1990.**

As can be seen in figure 35, the fuel savings in each of the scenarios are quite similar, about **0.6 to 0.7 MMB/D.** These results show that the effects of opposing factors influencing fuel consumption more or less cancel one another. In the base case scenario, vehicle travel increases and demand for fuel efficiency is low. But new car sales are high, so many older, less efficient cars are replaced. In the disruption scenarios, new car sales are depressed; but travel increases less rapidly, and those cars that are sold are more efficient than in the base case.

One could postulate other scenarios, in which high sales and demand for fuel efficiency are coupled with low or no growth in travel; and the fuel savings could be increased to about 1 MMB/D. Or one could combine low sales and no increase in new car fuel efficiency with increased travel, in which case the savings could drop to about 0.4 MMB/D. In OTA's judgment, however, the scenarios shown in figure 35 represent the most plausible combinations of circumstances.

If one assumes that the percentage increase in the efficiency of light trucks is half that of automobiles, due to the slower turnover of the fleet,[12] then fuel consumption by light trucks would drop by about 0.1 MMB/D under circumstances similar to those postulated for automobiles. Total savings from increased efficiency of automobiles and light trucks between 1985 and 1990 would then be about 0.7 to 0.8 MMB/D, and the total reduction in fuel demand for transportation would be 0.8 to 1 MMB/D.[13]

[12]Kulp and Holcomb, op. cit.

[13]This magnitude of fuel savings is consistent with a relatively constant demand for transportation services. A reduction or change in demand could also have a large effect, however. For example, if demand for transportation services drops by 10 percent across the board, fuel consumption would drop by an additional 0.9 MMB/D; and if 10 percent of the passenger-miles traveled by car shifts to buses, the savings would be around 0.2 MMB/D.

INDUSTRY

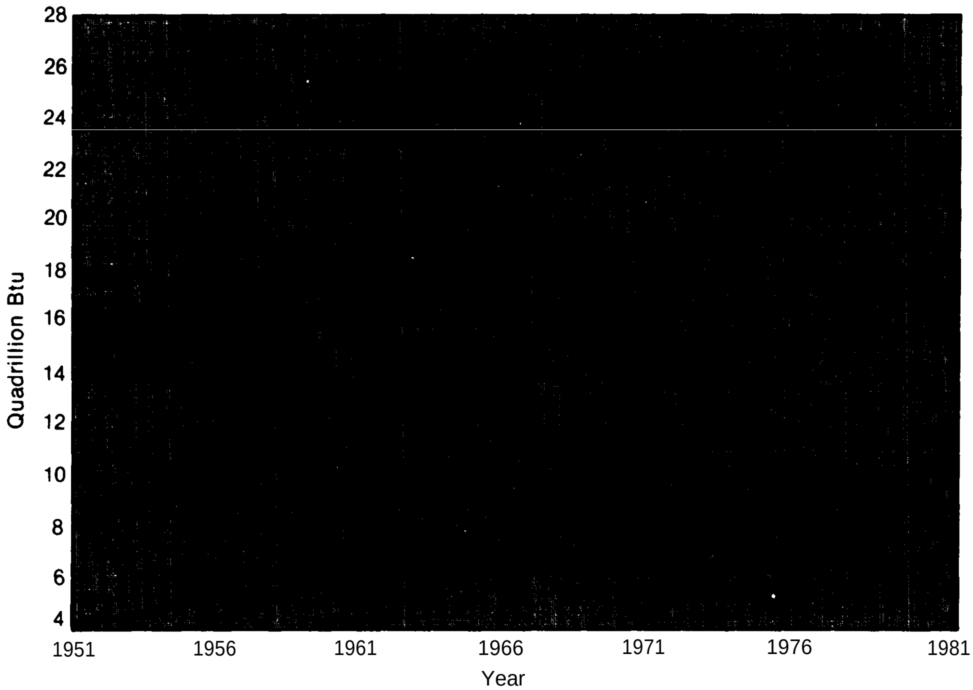
Since 1951, industrial use of energy in the United States grew from 17.4 quadrillion Btu per year (quads/y r), to almost 27 quads/yr by 1979. Since then, it has decreased rapidly to just over 21 quads/yr in 1983, although there are indications that industrial energy use is beginning to grow again.

In figure 36, the growth in industrial energy use reflects increases in the use of natural gas and petroleum fuels, and a decrease in the use of coal. The latter occurred because of the economic advantage of oil and gas compared to coal, including the environmental restrictions imposed on coal use in the 1970s. In 1950, coal was the largest source of industrial fuel, accounting for almost 40 percent of the energy used. Petroleum and natural gas accounted for approximately 25 percent each. By 1978, these shares had changed dramatically; coal accounted for only 12 percent of total industrial fuel, while petroleum had increased to nearly 40 percent. In terms of growth rates, total industrial energy use has grown at a rate of 1.7 percent per year between 1951 and 1979, and use of petroleum has grown at a rate of 3.5 percent per year. Coal use decreased at **2.7** percent per year. The absolute amount of petroleum used by industry rose from 1.96 MMB/D in 1951 to a high of 5.14 MMB/D in 1979.

It is apparent that 1978-79 was a watershed for energy use in American industry. Total final demand for energy fell from a 1979 high of 26.8 quads/yr (counting electricity at 3,412 Btu per kilowatthour [kWh]) to a 1982 level of 21.2 quads/yr. Oil fell from a 5.1 MMB/D industrial consumption level in 1979 to a 1982 level of 4.0 MMB/D. During this period petroleum's share of total energy use stayed approximately constant at 37 percent.

Table 20 lists the 10 most petroleum-intensive industries, as reported in the Department of Energy's 1980 *Industrial Energy Efficiency Improvement* annual report. These figures do not include petroleum basic feedstocks. The great-

Figure 36.–Industrlal Energy Demand, 1951-81



SOURCE: Energy Information Administration.

Table 20.—Industrial Users of Residual Oil for Fuel–1980

Industry	Petroleum use (thousand B/D)
1. Paper and allied products	169
2. Petroleum and coal products	133
3. Chemicals and allied products	99
4. Primary metals ., , ...	72
5. Food and kindred products	34
6. Stone, clay and glass products	22
7. Transportation equipment	17
8. Textile mill products.	9
9. Rubber and miscellaneous plastics . . .	7
10. Machinery, except electrical	6

SOURCE: *Industrial Energy Efficiency Improvement Program: Annual Report to the Congress and the President 1980,* **Department of Energy, Office of Industrial Programs, Washington, DC.**

est quantity of petroleum was consumed by the paper and allied products industry (SIC[14] 26), even though this industry was about so percent self-sufficient through the use of biomass as fuel. Note also that the top four petroleum-consuming industries account for over 80 percent of all residual fuel oil used in industry. This means that if petroleum use is to be curtailed or made more efficient, these four industries must play a large part.

OTA has made projections of the trends in fuel use which should occur by the year **2000, given a set of fuel prices that increase modestly but pro**gressively over that time span. These projections were reported on extensively in OTA's report on Industrial Energy Use.[15] OTA projected that total industrial fuel use will increase above current levels, but at a rate much lower than the rate of growth of industrial output. The share of petroleum-based fuel is projected to decline from its current level of 37 percent of all industrial fuel to less than **30 percent by the year 2000.**

Technologies Available to Reduce Oil Dependence

A number of technologies are now available whose widespread implementation could extensively reduce oil use by U.S. industry. Those technologies can be broken down into two broad areas: general technologies, such as those for heat recovery which are applicable to many industries; and specific technologies for particular industries.

General technologies include the following:

1. **Housekeeping** covers those things industry can do to improve the efficiency of energy use with a minimum of monetary investment. Items included would be routine maintenance of steam lines to prevent loss of steam through inoperative traps, switching off equipment not needed, and adjusting heat, ventilation, and air-conditioning systems for optimum performance at minimum cost .

2. **Computer control systems** either are added to improve the performance of an existing boiler system used to raise steam, or added to an industrial process to monitor a production line to see that feedstock material is not wasted and to ensure product quality. Addition of computer control systems to boilers allows the close monitoring of air and fuel so that unneeded air is not heated and unneeded fuel is not burned. In a production line, a computerized process control system can be used to optimize such things as paper thickness, polymer color, or petroleum viscosity. A number of parameters can be monitored simultaneously.

3. Waste heat recovery systems are available to improve the overall efficiency of energy use by recovering heat from combustion gases in a steam boiler or by recovering excess thermal energy from a process stream product. For example, when petroleum is first distilled, large quantities of energy are used to fractionate crude oil into different boiling-range components. However, the resulting distillates may not need to be so warm, Therefore, a heat exchanger can be built into the process stream to allow crude oil feedstock to absorb some of the thermal energy from the distillate before being introduced to the distillation unit, resulting in less energy being needed to fractionate the feedstock.

Another approach to heat recovery involves upgrading thermal energy to a level which can be useful as a heat source. A large amount of industrial energy is lost from process streams at temperatures less than 300° Celsius. To use such energy, vapor-recompression or heat pumps are

[14] SIC means **Standard Industrial Classification of the U.S.** Depart**ment of Commerce.**

[15] *Industrial Energy* **Use (Washington, DC: U.S. Congress, office of Technology Assessment,** OTA-E-198, June **1982).**

needed to raise this low temperature heat to a more useful temperature and pressure. In terms of Btu, low-level heat has enormous potential to improve industrial energy efficiency.

Many industries have energy conservation technologies available to them that are unique to that industry. Below are some categories of technologies available to four of the most energy-intensive industries.

1. **The Chemicals and Allied Products Industry.** Technologies available for reducing petroleum dependence in the chemicals industry exist in two broad areas. The first involves improvements in physical separation technology, specifically the modification and possible elimination of distillation as a chemical separation technique. Incremental improvements in the distillation process, retrofitted to existing installations, already have achieved significant (e.g., 25 percent) savings in many plants. Further improvements of comparable magnitude could be made.

Alternative approaches to liquid separation are on the horizon, and could be implemented if distillation costs were high enough. These techniques include freeze crystallization separation, vacuum distillation, and liquid-liquid (solvent) extraction. The latter is a most promising technique, entailing the use of a solvent with a high affinity for one component of a chemical mixture, but immiscible with the remaining components. Using this technique, separation involves two steps: decanting and closed-loop evaporation/condensation of the solvent. One company has already used the technique in a synthetic fiber plant, saving an estimated 40,000 barrels of oil equivalent annually.

Production integration technologies also are available for improving petroleum use efficiency in the chemicals industry. Perhaps the simplest example is cogeneration of steam and electricity.[16] However, many other opportunities exist, notably in integrating chemical production into petroleum refining complexes. Also, integration of the production of ethylene, propylene, and a wide range of petrochemicals from a naphtha-based (aromatics-based) scheme is a strong possibility by 1990. Another option would be to integrate ethylene and acetylene production with ammonia and/or methanol. Ethylene/acetylene coproduction will become increasingly attractive as distillate prices rise and heavier feedstocks are used.

2. **The Petroleum Refining Industry.** The petroleum refining industry uses about 10 percent of its crude oil throughput as fuel for the various refining processes such as distillation and cracking. Since one of the assumptions of this study is that there is a sustained shortfall of 2.2 MM B/D in crude oil (an additional 800,000 B/D of imported petroleum products, mostly residual fuel oil, are also lost), it follows that the refining industry would use about 200,000 B/D less as fuel. This is probably conservative, since undoubtedly the most inefficient refining operations would be the ones shut down in a curtailment.

In addition to the lowered throughput, many of the technologies applicable to Chemicals and Allied Products can also be used in petroleum refining, And given the large amounts of low-level heat produced by refineries, there is the possibility of both thermal and mechanical recovery of heat using either new designs for production units or heat pumps.

3. **The Paper and Allied Products Industry.** The paper industry is now over 50-percent energy self-sufficient through using wood residue and spent paper pulping liquor as production fuel. One of the most efficient means of improving energy use in the industry would be to retire older equipment. The paper industry is unique in that much of its equipment is very long-lived, some as much as 50 years. New technologies available to the industry include continuous digesters for pulp production, cogeneration of steam and electricity or steam and mechanical drive, and new papermaking processes that reduce the amount of water that must be removed in drying.

4. **The Iron and Steel Industry.** Efficiency improvements in the iron and steel industry will involve simultaneous phasing out of older ineffi-

[16] Cogeneration is the simultaneous production of both electrical or mechanical power and thermal energy from a single energy source. A detailed discussion of promising cogeneration technologies can be found in *Industrial and Commercial Cogeneration* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-E-192, February 1983).

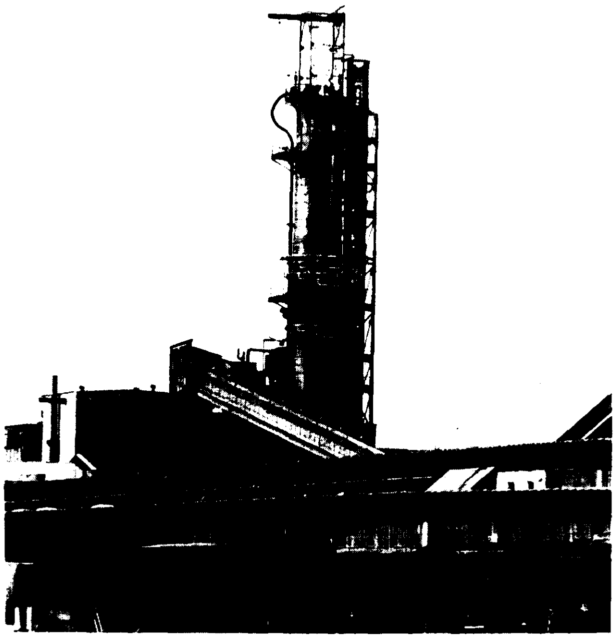


Photo credit: International Paper Co.

Paper and pulp are made from wood chips in an energy-efficient continuous digester

cient plants and equipment and the widespread introduction of the new technologies of electric arc furnace (EAF), minimills that recycle large amounts of scrap steel, and continuous casting (CC), which eliminates the cooling-reheat cycle for making intermediate steel products such as blooms and billets. The recent worldwide recession and resulting manufacturing overcapacity is forcing steel manufacturing firms to eliminate open hearth furnace operations in favor of EAF and CC technologies. However, while these new technologies will make steel making more efficient, they will not have a dramatic impact on petroleum use since only 7 percent of the energy used for steel making is petroleum.

Energy Conservation Potential of Industry

Industry has the potential to replace about 25 percent of its 1985 evel of fuel oil consumption through increased efficiency and process changes over a 5-year period after the onset of an oil shortfall, while maintaining production levels. The analysis underlying this projection, much of which was carried out in support of OTA's recently published *Industrial Energy Use* report, is based on an engineering and economic computer model called "ISTUM," the industrial Sector Technology Use Model which OTA used to examine the four most energy-intensive industries in U.S. manufacturing. For these industries, potential oil and natural gas savings were calculated for investments that would minimize total energy use per unit of production.

In the OTA report, oil and gas prices were postulated to increase an average of 3.5 percent per year between 1980 and 2000, while coal and electricity prices remained relatively constant. Product output for the entire industrial sector was assumed to grow at a rate of **2.9** percent per year. Energy use was then calculated to grow at one-third of this rate—i.e., 1 percent per year.

In the case of an oil supply shortfall, many anomalies would occur. Oil prices would quickly and dramatically increase, and industrial output would likely decline as overall demand for industrial products declined. In addition, the decline in crude oil supplies would result in a drop in refining throughput. The effect of these anomalies on oil consumption has been approximated through the following assumptions:

- increased prices of oil fuels would accelerate investment in energy conservation projects by manufacturing firms if they choose to remain in production. This analysis assumes that energy-efficiency improvements that took place over 10 years in the original OTA projection (1985-95) would be achieved in 5 years—i. e., by 1990.
- Output from the major oil-consuming industries (except refining) will remain flat on the average for this 5-year period.
- Opportunities for the improvement of petroleum fuel use efficiency will be roughly comparable to that of the pre-disruption case. Even though OTA assumed that production output is not increasing, a certain amount of capital stock will still be replaced. To the extent that new equipment is used, it will be more energy efficient than the old equipment. Therefore, energy consumption per unit of output will decline over the 1985-90 time span.

- Refinery throughput will have decreased by about 2.2 MMB/D after 5 years, with an additional 800,000 B/D decline in imported residual oil.

By removing economic growth from the previous OTA results derived from ISTUM (for 1985 to 1995) and compressing those results from 10 to 5 years, we can account for the first two assumptions. We find, in this case, that about 250,000 B/D of distillate and residual fuel oil and liquefied petroleum gas (LPG) can be replaced between 1985 and 1990. In addition, the decline in crude oil throughput accounts for an additional 200,000 B/D, or a 0.4-quad decline in fuel use. The total of the two factors–conservation and lowered refinery through-put–is about 450,000 B/D, of which about one-third draws from the same pool of oil as was considered for fuel switching in the previous chapter.

In addition to oil savings, these conservation measures will also reduce natural gas use. Natural gas freed in this way can be used to replace oil requirements in industry and buildings not eliminated by conservation. Table 21 shows the projections of industrial energy conservation that can be achieved with each fuel over the 5-year period.

The final line in table 21 shows the conservation potential which is available in the event of an oil disruption. These figures show that 1.3 quads of natural gas could be saved, along with a total of 0.34 quad of petroleum-based boiler fuels. Under this scenario, coal, residual oil, and natural gas use was adjusted to eliminate fuel switching that was incorporated in the original ISTUM analysis. In addition, a correction was applied to the petroleum refining industry, to account for a decrease in conservation opportunities that would accompany a decrease in refinery throughput in that industry.

Projections of energy use for the four most energy-intensive industries were made for each technology within each industry, and these were totaled to project overall energy use by fuel within each of these industries. These projections were based on ISTUM modeling that analyzed energy use by dividing energy use into various energy service categories, a number of which are generic to all industries, while others are specific to a particular industry. Among the former are such categories as fuel for boiler-generated steam or fuel for heating, ventilation, and air-conditioning. Among the latter—specific to an industry—are those fuels for pulping of wood in the paper industry and crude oil distillation in petroleum refining. The numbers determined this way were then subjected to the same manipulation as described above for the energy of the total industrial sector—i.e., 1 O-year conservation measures are expected to be accomplished in 5, and there will be zero growth in each industry. In addition, petroleum refining industry fuel use has been cut by 200,000 B/D owing to decreased crude oil throughput.

In figures 37 through 39, OTA presents projections of the changes that are anticipated to occur in petroleum-based energy use, natural gas-based energy use, and total energy use within each of the four key energy-intensive industries. In the case of petroleum fuel use (fig. 38), the paper industry is projected to decline from a 1985 level of 130,000 B/D to a 1990 level of **86,500**

Table 21.—Fuel Use Projections (in quadrillion Btu)

	Natural gas	Residual oil	Distillate oil	Total residual and distillate oil	LPG	Coal
1985 use	6.94	0.98	0.33	1.31	0.46	1.70
1990 use	4.51	0.78	0018	0.96	0.29	2.83
1985-90 change	+ 2.43	-0.20	+ 0.15	+ 0.34	+0.16	—
Adjustment for fuel switching	+ 1.13	—	—	—	—	+ 1.13
Final fuel use conservation Potential	+ 1.30	+ 0.20	+ 0.15	+ 0.34	+ 0.16	0.00

SOURCE: Office of Technology Assessment.

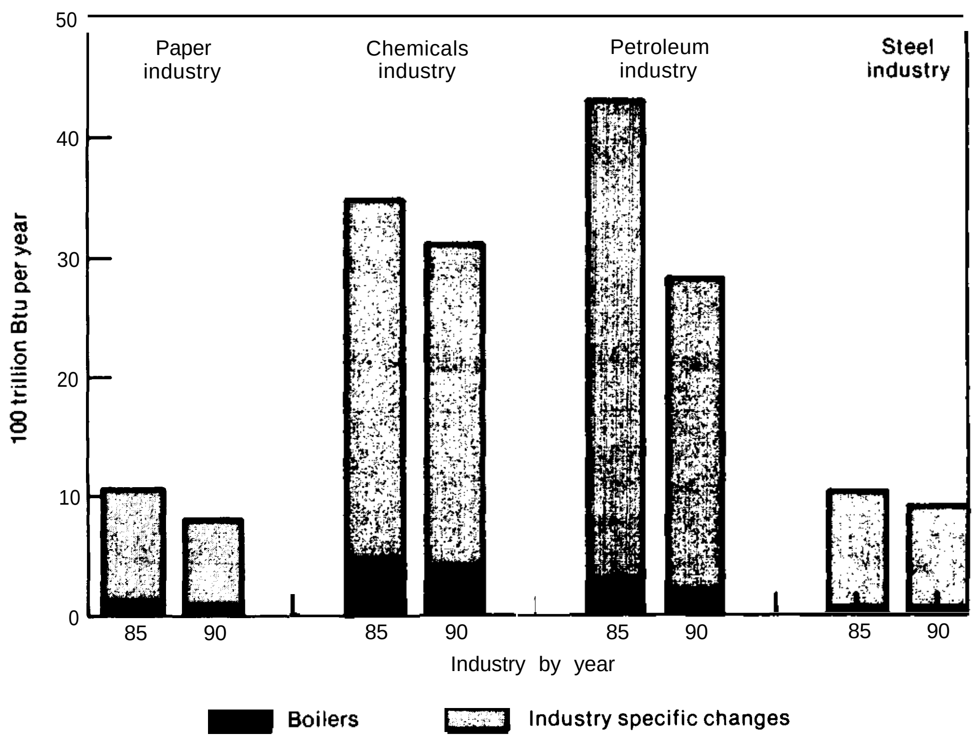
B/D, most of which will be used to raise steam. Much of that oil will be replaced by biomass fuels derived from wood feedstock. The chemicals industry is projected to reduce its petroleum fuel use by about 50,000 B/D over the 5 years, owing primarily to technological changes in the industry-specific categories.

In steel manufacturing, petroleum fuel use is projected to decline from 91,000 B/Din 1985 to less than 80,000 B/D in 1990, again reflecting technological change—i.e., to the penetration of EAFs.

Summary

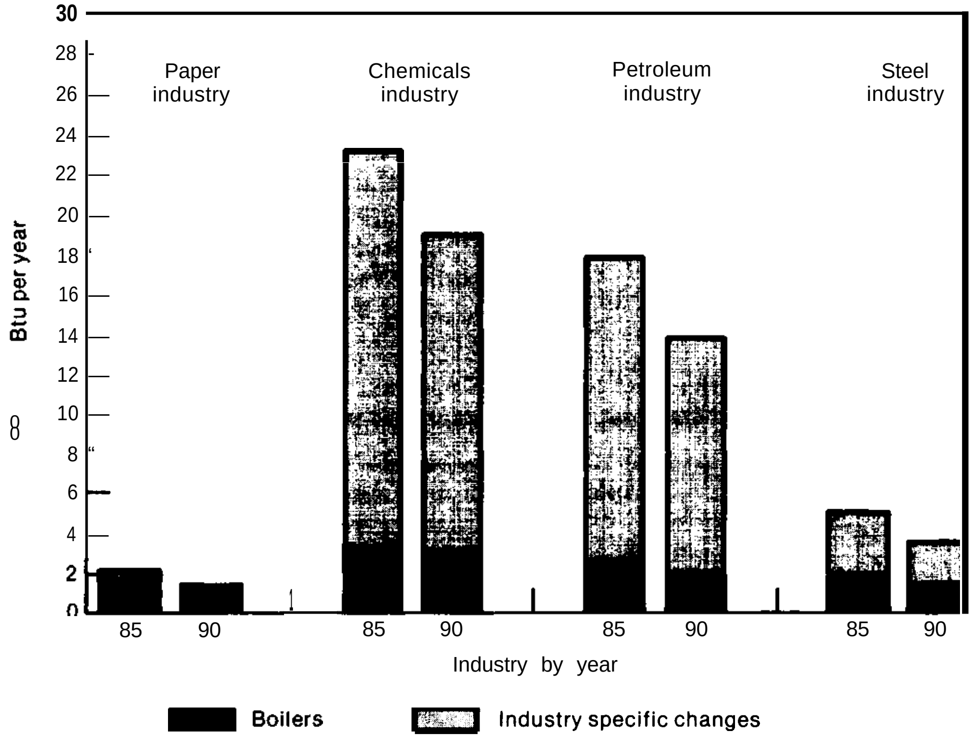
In summary, OTA has projected that U.S. industry is capable of a 250,000 B/D reduction in petroleum-based fuels in the 5-year period between a 1985 disruption and 1990, plus an additional drop of **200,000** B/D due to reduced refinery throughput. In addition, increased efficiency of natural gas use could save 1.3 TCF/yr of natural gas (equivalent in energy to 650,000 B/D of oil) in the same 5-year period.

Figure 37.—Total Fuel Use Projection (energy for four Industries)



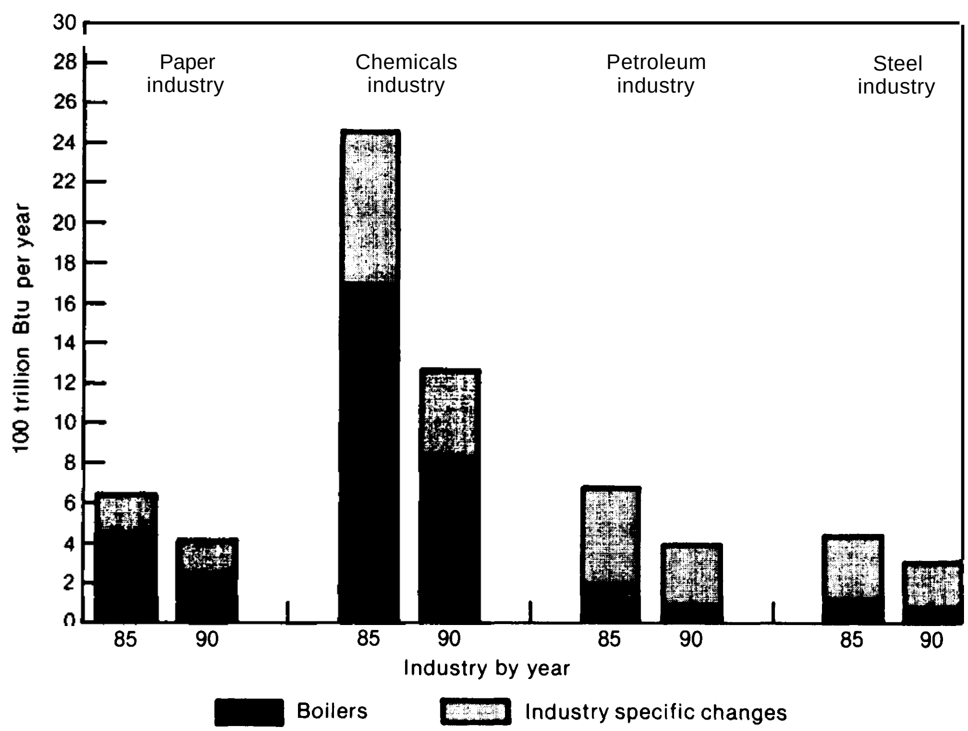
SOURCE: Off Ice of Technology Assessment.

Figure 3&—Petroleum Fuel Use projections (consumption by four major industries)



SOURCE: Office of Technology Assessment.

Figure 39.—Natural Gas Use Projections (consumption by four major industries)



SOURCE: Office of Technology Assessment.